Combined microsurgical and endovascular strategies have been used for more than a decade to treat complex intracranial aneurysms. Ongoing advances in endovascular techniques have increased the safety and efficacy of this modality of treatment, making it more attractive, especially for patients. As the field of endovascular neurosurgery evolves, interest in combined neurovascular teams has been renewed. Such teams select the optimal management strategy for aneurysms on a case-by-case basis.

A subset of intracranial aneurysms requires combined microsurgical and endovascular management. Ideally, a combined treatment strategy offers better results and leads to fewer complications than either treatment alone. Most importantly, the combined management plan should improve on the natural history of the untreated lesion. In this report we present our series of patients who were treated with a combined approach. Our goal was to identify the types of complex aneurysms for which such an approach is indicated.

**Object.** The purpose of this study was to assess the efficacy and describe the technical features of combined endovascular and microsurgical treatments for complex and giant unruptured intracranial aneurysms.

**Methods.** A prospectively maintained database was reviewed to identify all patients with unruptured intracranial aneurysms who were treated with combined techniques. Twenty-one lesions were treated in as many patients: six lesions involved the posterior cerebral artery (PCA); seven the cavernous portion of the internal carotid artery (ICA); two the basilar apex; two the basilar trunk; and one each the anterior communicating artery, anterior cerebral artery, petrous ICA, and cervical ICA. Aneurysms were treated with combined extracranial–intracranial bypass procedures and parent-vessel occlusion, flow redirection, or arterial transposition.

Aneurysm occlusion was achieved in 20 patients. In the remaining patient the aneurysm recurred, requiring stent-assisted repeated coil placement. Three patients suffered permanent neurological deficits related to treatment, and three died, two of whom had basilar trunk aneurysms.

**Conclusions.** Certain complex aneurysms may be treated optimally by combining endovascular and surgical procedures. A low incidence of complications follows treatment of anterior circulation aneurysms. Treatment of complex posterior circulation aneurysms is associated with a higher incidence of complications, although this likely reflects the more complex nature of these lesions. The risks of this combined treatment strategy are likely lower than the risks associated with the natural history of this subset of aneurysms.

**Key Words** • endovascular technique • complex aneurysm • giant aneurysm • revascularization • microneurosurgery
Patient Characteristics

There were 21 patients (eight men and 13 women) included in this study. Their mean age was 55.1 ± 13.7 years (mean ± standard deviation). Their median age was 55 years (range 22–73 years). Fourteen patients presented with symptoms related to mass effect of the aneurysm, two with headaches, and two with ischemia. Aneurysms were diagnosed incidentally in two patients (Table 1).

Aneurysm Characteristics

Of the 21 aneurysms, 11 (52.4%) were located in the anterior circulation and 10 (47.6%) were located in the posterior circulation. In the posterior circulation, six aneurysms (28.5%) involved the PCA, and two each (9.5%) the basilar apex and basilar trunk. In the anterior circulation, seven lesions (33.3%) involved the cavernous ICA, and one each (4.8%) the ACoA, the junction of the A2 and A3 segments of the ACA, the petrous ICA, and the cervical ICA. Factors contributing to the complexity of the lesions were identified and included nine giant, four dissecting, and four dolichoectatic aneurysms; previous clip occlusion of two lesions; a calcified neck in one; and significant scarring in one.

Treatment Modalities

Treatment decisions were made for all 21 patients after the cases were reviewed by the neurovascular team, which included two cerebrovascular surgeons (R.F.S., J.M.Z.) and two endovascular neurosurgeons (C.G.M., F.C.A.). Microvascular procedures included 17 extracranial–intracranial bypasses, two intracranial–intracranial bypasses, one arterial clip placement for flow redirection, and one transposition of the cervical ICA to facilitate endovascular therapy (Table 2). All but one of the endovascular techniques involved parent-vessel occlusion. One patient underwent stent-assisted coil placement.

Extracranial–Intracranial Revascularization and Parent-Vessel Occlusion

Eight patients harbored anterior circulation aneurysms that were treated with microsurgical extracranial–intracranial bypass followed by endovascular parent-vessel occlusion. Among these patients, all eight underwent an STA–MCA bypass for seven aneurysms involving the cavernous ICA, including one pseudoaneurysm related to transsphenoidal surgery and one involving the petrous ICA.

The six patients with PCA aneurysms were treated with

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>Indication for Op</th>
<th>Location of Lesion</th>
<th>Complicating Factors</th>
<th>Complications</th>
<th>Neurological Sequelae</th>
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<tbody>
<tr>
<td>1</td>
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<td>ataxia</td>
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<td>3</td>
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<td>none</td>
<td>none</td>
<td>48</td>
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<tr>
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<td>fusiform</td>
<td>EDH</td>
<td>homonymous</td>
<td>38</td>
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<tr>
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<td>51, M</td>
<td>mass effect causing dysmetria</td>
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<td>homieina, mild li hemiparesis</td>
<td>43</td>
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<td>6</td>
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<td>basilar trunk</td>
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<td>intraop rupture, EDH</td>
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<tr>
<td>7</td>
<td>65, F</td>
<td>CN III palsy + retroorbital pain</td>
<td>rt cavernous ICA</td>
<td>none</td>
<td>none</td>
<td>none</td>
<td>33</td>
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<td>8</td>
<td>61, M</td>
<td>lower CN deficits</td>
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<td>EDH</td>
<td>died</td>
<td>4</td>
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<tr>
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<td>lt PCA, P2</td>
<td>dissecting</td>
<td>none</td>
<td>none</td>
<td>6</td>
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<tr>
<td>10</td>
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<td>lt cavernous ICA</td>
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<td>none</td>
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<td>none</td>
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<td>rt cavernous ICA</td>
<td>giant</td>
<td>none</td>
<td>none</td>
<td>2</td>
</tr>
<tr>
<td>17</td>
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<td>CN III &amp; V palsy</td>
<td>rt cavernous ICA</td>
<td>giant</td>
<td>none</td>
<td>none</td>
<td>17</td>
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<tr>
<td>18</td>
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<td>CN III palsy</td>
<td>rt cavernous ICA</td>
<td>growing</td>
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<td>EDH, PCA</td>
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<td>19</td>
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<td>lt PCA, P2</td>
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<td>none</td>
<td>homonymous</td>
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<td>20</td>
<td>69, F</td>
<td>mass effect causing CN VI palsy</td>
<td>lt cavernous ICA</td>
<td>giant</td>
<td>none</td>
<td>none</td>
<td>12</td>
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<tr>
<td>21</td>
<td>51, F</td>
<td>stroke</td>
<td>rt ACA, A2–A3</td>
<td>large</td>
<td>none</td>
<td>none</td>
<td>5</td>
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</table>

* CN = cranial nerve; FA = femoral artery; FU = follow up; NA = not applicable.
extracranial–intracranial revascularization and endovascular parent-vessel occlusion. Six patients harbored aneurysms of the PCA (one giant, four dissecting, one fusiform; four of the P1–P2 junction; one of the P2 segment; and one of the P3/P4 junction), five of whom underwent an OA–PCA anastomosis followed by endovascular coil placement and occlusion of the aneurysm and PCA. The other patient underwent an OA onlay. The patient with a dissecting aneurysm at the P3–P4 junction of the PCA underwent an OA onlay, followed by endovascular balloon occlusion of the parent vessel. A patient with a giant basilar apex aneurysm was treated with coil embolization followed by an STA–SCA bypass.

Flow Redirection

Four patients underwent flow redirection procedures. A patient with a giant basilar tip aneurysm underwent clip placement on P1 away from the aneurysm to redirect flow. She later underwent endovascular stent placement in the BA and contralateral PCA and stent-assisted coil placement in the basilar trunk aneurysm. A patient with a large right A2 aneurysm underwent a pericallosal artery microsurgical bypass followed by endovascular parent-vessel occlusion of the right A1, to redirect flow through the aneurysm. Two patients underwent STA–SCA bypass and coil occlusion of the A1. Aneurysm Obliteration

Immediate postoperative angiography confirmed obliteration of the lesion in 20 patients and demonstrated residual aneurysm in the other one. Angiographic follow-up studies were obtained in 14 of the 18 surviving patients and demonstrated complete occlusion or stable residual aneurysm in 13 and a 1-cm enlarging residual lesion in one. The latter patient underwent stent-assisted coil placement in the residual aneurysm.

Postoperative Complications

Procedure-related complications occurred in eight cases. One patient had an occlusion of an OA–PCA bypass graft and a homonymous hemianopia developed; no treatment was given, and the deficit was permanent. Five patients suffered EDHs, all of which occurred after heparinization and endovascular treatment (Cases 1, 4, 6, 8, and 19). Among these, one patient (Case 6) presented in a coma and died shortly after evacuation of the EDH. Another patient (Case 8) died 3 months later of a brainstem stroke.

RESULTS

Clinical Outcomes

Fifteen patients (71.4%) had excellent outcomes, three (14.3%) had good outcomes, and three (14.3%) died (Table 2). One patient (Case 13) died of an underlying pulmonary malignancy. Another (Case 6) presented with ex-tensor posturing after intraoperative rupture of his giant basilar trunk aneurysm. He suffered a postoperative EDH and died of brainstem compression caused by the aneurysm. The third patient who died (Case 8) had experienced a brainstem stroke 6 years earlier. His giant basilar trunk aneurysm was treated with an STA–SCA bypass, followed by coil occlusion of the right VA distal to the PICA. Three months later, BA thrombosis developed on the morning that he was scheduled to undergo endovascular occlusion of the contralateral VA, and he died.

The mean follow-up duration for the 18 surviving patients was 20 months (range 1–48 months). Eleven patients were symptom and disease free at follow-up review. Four patients’ symptoms were unchanged from presentation, including three who presented with mass effect and one who continued to suffer headaches. Three patients suffered mild strokes that resulted in a homonymous hemianopia after occlusion of their bypass graft.

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<table>
<thead>
<tr>
<th>Location of Lesion</th>
<th>Treatment</th>
<th>Outcome</th>
<th>Excellent</th>
<th>Good</th>
<th>Fair</th>
<th>Poor</th>
<th>Dead</th>
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<tr>
<td>cervical ICA</td>
<td>op transposition, endovascular stent, coil placement</td>
<td>1</td>
<td>(71.4%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>petrous ICA</td>
<td>STA–MCA bypass, coil occlusion of aneurysm &amp; parent vessel</td>
<td>1</td>
<td>(14.3%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cavernous ICA</td>
<td>STA–MCA bypass, coil occlusion of aneurysm &amp; parent vessel</td>
<td>2</td>
<td></td>
<td></td>
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<tr>
<td>ACoA</td>
<td>A1–A1 bypass, coil occlusion of inflow, aneurysm debulking</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>A1/A1</td>
<td>A1–A1 bypass, coil occlusion of rt A1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>basilar trunk</td>
<td>STA–SCA bypass, coil occlusion of VAs</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>basilar tip</td>
<td>STA–SCA bypass, coil occlusion of VAs</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>PCA</td>
<td>OA–PCA bypass, coil occlusion of aneurysm &amp; vessel</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>OA onlay</td>
<td>OA onlay, coil occlusion of aneurysm &amp; vessel</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>
Homonymous hemianopia developed in three patients treated with OA–PCA revascularization (Cases 1, 4, and 19). In one (Case 1) the complication resolved completely; in one (Case 19) an occlusion of the graft developed and this patient was found to have a left PCA infarct, and in one (Case 4) a mild permanent visual field deficit was found. In one patient (Case 18) a pseudoaneurysm developed at the femoral artery after a cavernous ICA aneurysm was treated with coils. One patient (Case 2) required placement of a ventriculoperitoneal shunt after surgery to control increased intracranial pressure.

ILLUSTRATIVE CASES

Case 16

This 65-year-old woman had a 3-month history of progressive proptosis, double vision, and intermittent headaches. Magnetic resonance imaging and magnetic resonance angiography revealed a mesial right temporal mass, and four-vessel angiography demonstrated a giant cavernous ICA aneurysm (Fig. 1A).

A right STA–MCA bypass was performed, and patency was documented using intraoperative angiography. Three days later the patient tolerated temporary test occlusion of the right ICA. Seven GDCs were inserted into the petrous and high cervical segments of the right ICA (Fig. 1B and C). Complete occlusion of the vessel was documented, and a right external carotid artery injection demonstrated excellent filling of the distal MCA branches through the bypass graft. At her 6-month follow-up examination, the patient reported resolution of her symptoms. Angiography confirmed obliteration of the aneurysm and patency of the bypass graft.

Case 13

This 51-year-old woman with a history of lung cancer presented with the sudden onset of slurred speech and weakness of the right arm. Imaging studies revealed a calcified basilar apex aneurysm extending into the third ventricle (Fig. 2A) and an infarction of the left temporal lobe and posterior aspect of the left subinsular cortex. A three-stage approach, including clip placement, endovascular stent insertion, and embolization was recommended.

During surgery, the neck of the aneurysm could not be clipped satisfactorily because of the extensive thrombosis and calcification at its base. Therefore, the P1 segment of the right PCA was clipped as it emerged from the base of the aneurysm. The posterior communicating artery reconstituted the distal right PCA (Fig. 2B). The second stage of treatment was stent placement. After the initial angiograms were obtained a 3 × 14-mm stent (Radius; Boston Scientific, Watertown, MA) was placed, extending from the left PCA down to the BA proximal to the SCAs. Three weeks later, the residual aneurysm was embolized with seven GDCs, which were placed without incident (Fig. 2C and D). The patient later died of her underlying malignancy.

Case 19

This 65-year-old man had received a diagnosis of a giant left PCA aneurysm 3 years earlier and had been told that the lesion was inoperable. He presented to us with progressive decline, including dizziness, right hemiparesis, and intermittent diplopia. Angiography confirmed the presence of the aneurysm (Fig. 3A), and an OA–distal PCA bypass followed by coil embolization of the distal P2 segment of the PCA was recommended.

Initially, the patient underwent a bioccipital craniotomy and microsurgical anastomosis of the right OA to the distal PCA. Two days later angiography demonstrated patency of the bypass, and the patient underwent coil embolization and occlusion of the aneurysm and parent artery (Fig. 3B and C). Seven GDCs were deposited within the aneurysm. Subsequent angiography demonstrated filling of the PCA through the bypass graft but no filling of the aneurysm from the VA injections.

The patient’s postoperative course was complicated by an occipital EDH, which caused right homonymous hemianopia. The hematoma was evacuated and the patient’s left visual field cut resolved. At 1-year follow-up examination, the patient had resumed all activities of daily living.

DISCUSSION

Combined endovascular and surgical therapy has been practiced since 1987.19 Early applications of endovascular...
therapy as a surgical adjunct included embolization of vascular lesions before resection. This approach made it possible to obliterate extensive portions of vascular malformations and tumors and thus enhanced the feasibility of resection. Combined techniques have also been applied to the treatment of intracranial dural fistulas and vascular occlusion. The classic application of the combined technique is an extracranial–intracranial bypass combined with endovascular parent-vessel occlusion. First attempted in 1987, Serbinenko, et al., described this technique in 1990 after treating nine patients with giant ICA aneurysms for whom direct clip occlusion was deemed to be associated with an unjustifiably high risk. Early combined treatment strategies also included endovascular retrograde suction decompression of paracrioclid aneurysms to facilitate dissection and direct clip occlusion. The use of balloon occlusion of the ICA before dissection of unruptured aneurysms allowed proximal artery control for temporary occlusion without requiring neck dissection for proximal control of the ICA.

The overwhelmingly poor prognosis associated with untreated giant and complex aneurysms mandates aggressive treatment in which both microsurgical and endovascular techniques are used. In this series, combination therapy was performed safely and aneurysms were obliterated successfully in most cases. The use of such techniques significantly alters the natural history of these lesions.

The combined endovascular and surgical treatment paradigms typically fall within one of four categories, as follows: 1) endovascular or surgical treatment after unsuccessful prior surgical or endovascular treatment, respectively; 2) endovascular treatment of the remote second aneurysm; 3) endovascular proximal parent artery control during surgery for clip occlusion/decompression; and 4) combined surgical and endovascular treatment for complex intracranial aneurysms (for example, microsurgical revascularization followed by endovascular parent-artery occlusion and flow-redirection techniques).

Barnett, et al., Lawton, et al., and Hacein-Bey, et al., published large contemporary series of patients treated with a combined modality. In this report, we reviewed only the subset of patients who received the aforementioned fourth treatment paradigm. Specifically, endovascular and surgical modalities were combined in the initial treatment plan. Broadly, these patients may be categorized in the following subgroups: 1) those with aneurysms involving the petrous, cavernous, or paracrioclid ICA that are not amenable to direct surgical clip occlusion and that require

![Image](https://via.placeholder.com/150)

**Fig. 2.** Case 13. Cerebral angiograms and artist’s rendering depicting the posterior circulation. A: Anteroposterior view demonstrating a large basilar apex aneurysm. B: Anteroposterior view of the aneurysm after microsurgical clipping of the right P2 segment of the PCA. Subsequently, a stent was placed extending from the distal BA to the left P1 segment of the PCA. C: Angiogram obtained when the patient returned for further endovascular obliteration of the aneurysm with seven GDCs 3 weeks after placement of the stent. D: Illustration depicting the combined technique.

![Image](https://via.placeholder.com/150)

**Fig. 3.** Case 19. Cerebral angiograms and artist’s rendering depicting the posterior circulation. Left: Anteroposterior view demonstrating a large right-sided P1/P2 junction aneurysm. Center: Anteroposterior view of the aneurysm after OA–PCA bypass and coil embolization and occlusion of the lesion and parent artery. Right: Illustration depicting the combined technique.
an STA–MCA bypass or a cervical carotid artery–MCA saphenous vein bypass graft followed by parent-vessel occlusion; 2) those with aneurysms in the posterior circulation that require an STA–SCA or OA–PCA bypass; and 3) those with complex aneurysms that cannot be eliminated from the circulation and that require flow-redirection techniques. In our series, the most common aneurysms for which a combined technique was required were those involving the cavernous ICA and PCA. Of the latter, most were dissecting aneurysms.

Treatment of ICA Aneurysms

The technique for combining endovascular and surgical approaches to treat ICA aneurysms (Fig. 1C) has been well described. We treated 12 patients by using an STA–MCA bypass or cervical ICA–MCA saphenous vein bypass graft, and all had excellent outcomes.

Treatment of PCA Aneurysms

Revascularization followed by parent-vessel occlusion was the modality used to treat PCA aneurysms. The PCA aneurysms were difficult to access and their morphology was complex; four were dissecting aneurysms, one was fusiform, and one was a giant lesion. These patients underwent OA–PCA microanastomosis followed by embolization and occlusion of the aneurysm and parent vessel (Fig. 3C). One patient underwent an OA onlay instead of a bypass because of a poor-quality recipient artery.

The technical difficulty involved in the performance of an OA–PCA bypass may be greater than that for STA–MCA, as evidenced by the fact that homonymous hemianopia developed in four patients after PCA occlusion. Nevertheless, this deficit improved or resolved in two patients and was permanent in only one. The postoperative course in three patients treated for PCA aneurysms was complicated by EDH, underscoring the frequent but unfortunately necessary risk associated with heparinization during the endovascular treatment stage.

Flow Redirection

Flow-redirection techniques were used for aneurysms involving the BA and the ACAs. When an aneurysm cannot be removed from the circulation, the goal is to alter the hemodynamics at the lesion by changing the direction of blood flow.

The two patients with complex aneurysms involving the trunk of the BA were treated using flow reversal. The first procedure consisted of revascularization through an STA–SCA bypass, followed by a two-stage endovascular treatment. The second patient underwent procedures consisting of unilateral occlusion of the VA proximal to the PICA, followed by contralateral VA occlusion distal to the PICA. The goal in delaying occlusion of the second VA was to provide the graft with time to mature. Ultimately, one PICA depends on backflow from the BA, and this demand is thought to help prevent basilar thrombosis, thus maintaining flow from the bypass to the BA and the brainstem perforating vessels.

In both patients for whom this strategy was selected, postoperative EDHs developed, and neither individual survived long enough for the second endovascular procedure to be performed. One patient required a decompressive craniectomy and recovered from this procedure during his prolonged hospitalization. He died 3 months later of a posterior fossa stroke caused by BA thrombosis suffered on the day he was scheduled to undergo the second stage of endovascular treatment. One patient with a basilar apex aneurysm was treated with flow redirection entailing surgical clip occlusion of the right P, segment of the PCA, followed by stent placement in the distal BA and left PCA, followed in turn by stent-assisted coil embolization of the aneurysm (Fig. 2D). This patient eventually died of an underlying malignancy, although her postoperative course was excellent.

Two patients underwent flow-reversal techniques for ACA aneurysms. One had an A–A, aneurysm and the other had an ACoA aneurysm. Both patients underwent A–A, bypass followed by endovascular occlusion of the aneurysm and feeding artery.

Arterial Transposition for Stent Placement

A combined technique also may be indicated when an aneurysm is amenable to endovascular treatment but the tortuosity of the feeding artery renders access to the lesion impossible. One patient underwent transposition of a tortuous ICA to straighten the segment containing the aneurysm. Stent placement in the parent vessel and coil occlusion of the aneurysm were then possible.

Conclusions

Certain complex aneurysms may be treated optimally by combining endovascular and surgical techniques. Cavernous ICA aneurysms are classic examples, wherein treatment consists of an extracranial–intracranial bypass and endovascular parent-vessel occlusion. A similar strategy may be indicated for complex PCA aneurysms. In this case an OA–PCA bypass is performed, and the PCA is occluded endovascularly at the location of the aneurysm.

Finally, flow-redirection techniques may alter the hemodynamics of aneurysms that are not amenable to removal from the circulation. This treatment may be indicated for giant dolichoectatic lesions of the posterior circulation. Although the surgical and endovascular procedures emphasized in this combined paradigm are associated with well-known complications, the high-risk nature of the primary lesion mandates an aggressive approach. The risks of this combined treatment strategy are likely lower than those associated with the natural history of this subset of aneurysms.

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References

Combined management of complex aneurysms


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Address reprint requests to: Felipe C. Albuquerque, M.D., Neuroscience Publications; Barrow Neurological Institute, 350 West Thomas Road, Phoenix, Arizona 85013. email: neuropub@chw.edu.